TOPEX/POSEIDON Battery Performance and Management Techniques

F. Deligiannis, S. Di Stefano and G. Halpert, Energy Storage Systems Group,
Jet Propulsion Laboratory, California Institute of Technology,
4800" Oak Grove Dr., Pasadena, CA 911 (N

The TOPEX/POSEIDON spacecraft was launched successfully on August 10, 1992. The Satellite is powered by the Modular Power Subsystem (MPS) containing 3 NASA Standard S() Ah capacity batteries manufactured by McDonnell Douglas. The cells were manufactured by Gates Aerospace Batteries (GAB) in April 1991. Prior to launch, two other recently launched NASA satellites were experiencing battery problems, the Gamma Ray Observatory (GRO) and the Upper Atmosphere Research Satellite ((JARS). Both satellites were exhibiting large divergence on the half-battery voltages monitored. Eventually, one of the GRO battery half-voltages reached a limit of 750 V (an indication of an internal cell short) and was removed from the charging bus. Following this event, battery management techniques were applied to both spacecraft to correct the anomaly.

Prior to the TOPEX launch. the Battery Management Team was formed. The team recommended certain operational actions for the TOPEX satellite. It was believed, that some of the factors influencing this type of anomalous behavior of the batteries were: excessive overcharge and high peak charge currents. In order to better manage the batteries, a tender loving care (TI <C) mode of operation was recommended. The TLC mode included the following actions:

1. Avoid excessive overcharge by managing the V/T levels of operation during the occultation periods. Maintain the C/D ratio of the batteries within recommended limits.

2. Limit the peak charge current to 20A maximum. offset the solar array from normal to the sun.

3. Avoid high charge currents during full sun periods by operating at lower V1'levels.

4. Switch 10 the lower current sensor for amperehour integration to improve C/1) ratio accuracy.

As pari of the TOPEX battery management, some important battery parameters arc monitored seven days a wink. These parameters arc trended and compared to the GRO, UARS, EUVE satellite battery data and inhouse test data from two cell packs cycled under simulated TOPEX orbit regimes.

The TOPEX spacecraft has an orbit of approximately 112. minutes with eclipse durations varying from () to 35 minutes. The occultation periods arc 45 and 90 days long with 20-day full sun periods between them. This regime repeals throughout the duration of the mission. This paper covers the trend analysis of data for the first two occultation periods (Aug. 1992 - January 1993),

Listed below arc some of the battery parameters which have been trended from launch.

C/D ratio. The charge input over the discharge output for each orbit.

Net overcharge. The charge input to the battery after reaching 100% slate- of-char~,c measured in amp-minutes.

Peak charge current. The current during the initial part of the day when the solar array is at the coldest temperature measured in amps. This is the highest current available for charging the batteries.

Taper current. The current at the end of day measured in amperes.

Voltage **differential.** The difference between the voltage of cells 1 through 11 and the voltage of cells 12 through ?2 measured in millivolts. Traditionally [his parameter remains below 50 mV until the end-of-life of the battery at which time it increases to higher levels.

End-of-night battery voltage. The battery vol (age at the end-of-night. This voltage is the lowest during the orbit.

Battery temperature. '1 'he temperat uc of each battery monitored at the top of each battery in degrees celsius.

The Tender Loving Care Mode

During the first six months of the TOPEX/POSEIDON mission the Battery Management Team was actively recommending actions to be taken 10 operate the batteries under the recommended TI .C mode. Fig. 1 is a pictorial representation of the siginificant events that took place during the first two occultation periods.

The peak charge current was reduced from approximatel y 30 A to approximatel y 19 A by offsetting the soi ar array by 57.5°. '1 'he overcharge 10 the batteries was minimized by operating at various V/T level. During full sun operation the V/T level was set at 2, during orbits with eclipse duration below 28 minutes the V/T level was set at 3 and during orbits with eclipse durations above 28 minutes the V/'l' level was set at 4.

'1'rend A nalysis

C/1) Ratio
This parameter monitors energy balance and overcharge. The recommendation prior to launch was to maintain the C/D ratio to 105+ 3%.

Fig. ? illustrates the trended C/D ratios for each orbit of the first occultation period (8/29/92 through 10/7/9?). The C/D ratio during this period was maintained within the recommended guidelines and on an average did not exceed 108.5. All batteries remained within family.

The differences in the C/D values among the three ball teries was accou nted by t he di fferences in the three high current sensors used for monitoring the individual battery current above 3 A and the low current sensors used to monitor the battery current below 3 A. The C/1) parameter is unreliable in the region of small eclipse durations duc to the large error introduced in the calculation of the ratio during these small depth-of-discharge(DOD) periods. During these periods (which occur for a fcw days at the beginning and at the end of each occultation period) a more reliable parameter to monitor is the net overcharge.

Fig. 3 illustrates the trended C/D ratios for each orbit of the second occultation period (10/27/92 through 1/28/93). The C/J) ratios during this period remained within the same levels as the first occultation period 11 is shown from the figure that the V/T level change during the center of the occultation period (eclipse time Icss than 28 minutes) was successful in maintaining the C/D ratio within the recommended levels.

Calibration coefficient changes in the ground system and the PMON (Power Monitor) on the satellite were implemented during this period to reflect a better accuracy on the high and low current sensors, The PMON changes influenced the calculation of the C/D ratio and the net overcharge parameters. This is reflected in the C/D trend data during 1)0% 346 when the C/1) of battery #2 and #3 incl-cased and the C/D of battery # 1 decreased. From that day on the C/1) rat ios of all three bat (cries appeared to be withi n a narrower range. The ground coefficient changes influenced the conversion into engineering units of the high and iow battery currents. This change had no influence on the C/D ratio and the net overcharge parameter.

It may be noted that peaks in the C/D ratio were observed whenever changes to the V/T level were made. When the V/T level was increased the C/D ratio for a fcw orbits would increase to as high as 130. When the V/T level was decreased the C/D ratio would decrease for a fcw orbits 10 as low as 90. These peaks in C/1) ratio were explained as shifts in the electrochemical slate-of-charge of the battery, as the battery was increased to a higher V/T level of operation the battery would require a certain amount of overcharge to reach a higher electrochemical s(ate-of-charge and vice versa.

Same type of peaks in the C/1) ratio were observed during maneuvers. During the orbit of the maneuver the time within the orbit was not sufficient to totally recharge the battery (low C/D) to the same level. The immediate orbit after, the batteries were accepting a higher level of charge (high C/D) (0 compensate for the losses from the previous orbit.

Net Overcharge
"1 he Net Overcharge monitors the total excess energy input to the batteries and it may be correlated to battery wearout. This parameter is directly related to the C/D ratio parameter. However, it is considered more accurate than the C/D parameter during the low DOD eclipse orbits.

Fig. 4 exhibits the net overcharge during the first occultation period. The net overcharge fall three batteries did not exceed 30 amp-minutes which is less than 1% of the name plate capacity of each battery.

Fig. 5 exhibits the net overcharge during the second occultation period. During this period the net overcharge parameter again did not exceed 30 amp-minutes. During V/T level changes, peaks in the net overcharge parameter were observed for the same reasons outlined in the above section.

All three batteries were within the same range during both occultation periods. On DOY 346 the PMON modifications influenced the net overcharge parameter in an identical way as the C/D parameter. From that day on the net-overcharge parameters for all three batteries were in a narrower range. overall this parameter verified that the halt cries were neither over-charged nor under-charged.

Peak Charge Current
The peak charge current was monitored and maintained below the recommended ?.() amp limit. This current varies as a function of the power output of the solar array.

Fig. 6 and 7 exhibit the peak charge current trend data for each orbit during the first and second occultation period respectively, Initially the peak charge current was as high as 22 amp with the solar array offset at 55°. As the eclipse time increased the solar array temperature decreased, therefore, the solar array power output increased. This determined the change of solar array offset angle to 57.5°. The 57.5° angle was maintaining the peak charge current to the batteries under 20 amps.

DOY 268 the satellite was placed in a safehold mode of operation due to a parameter error in the Attitude Determination and Control Subsystem (ACS). During this mode of operation, the solar array was moved normal to the sun, (Ibis condition lasted for 4 orbits) consequently the charge current peaked to 30 amps which is the current limit of the Standard Power Regulating Unit (SPRU). Since the duration of this condition was so short, no effect was seen on the battery performance,

The satellite normally would go into no yaw steering between beta prime values of + 15° and -15°. However, during DOY 364 the satellite was placed in the no yaw steering mode at beta prime -123°. This resulted in a lower peak charge current during that period of time.

During the shorter eclipse durations the peak charge current decreased to as low as 12 amps. This occured, due to the fact the DOD was low and the batteries (which were almost fully charged) reached the V/T level voltage faster than the current could reach its maximum limit.

Taper Current
The taper current of each battery was monitored through the two occultation periods. This current is the current the batteries require to maintain the charge voltage during the constant voltage charging portion of the day. This parameter may be used as a battery efficiency indicator.

Fig. 8 and 9 exhibit the taper current for each battery during the first and second occultation period respectively. The taper current varies as a function of the operating V/T level. The higher the V/T level the higher the taper current. This is exhibited in the trended data of both occultation periods. During the V/T level transition for approximate.ly the same eclipse duration a higher current is required at the higher V/T level. The taper current also varies as a function of time available for charging. The longer the charging time the lower the taper current. This is exhibited in both figures where the taper current trend data reflects the shape of the curve of the eclipse duration. At the maximum eclipse duration of 35 minutes the taper current reached a maximum of approximately 600 mA. The taper current of the second occultation period remained at the same levels exhibited during the first occultation period. All three batteries remained within the same range and none experienced any unusual behavior. However, the taper current will be increasing as the batteries age because the efficiency of the batteries decreases and the internal impedance increases.

Voltage Differential

The voltage differential parameter has historically been trended 10 evaluate battery state of health. The voltage differential is the difference of the two half-battery voltages. Historically, this parameter would remain under 100 mV until the end-of-life of the battery.

Fig. 10 and 11 exhibit the voltage differential of battery # 1 for each orbit for the first and second occultat ion period respecti vc1 y. The volt age differential of battery # 1 remained under 2(I mV at all times. During the taper charge portion of the orbit the voltage differential was at () mV, during the peak power tracking it increased to 11 mV and during the discharge it decreased back 10 () mV.

1)uring the smaller duration eclipse periods the voltage di fferent i al exl ibited cusps during the peak power charging portion of the orbit. These cusps tended 10 disappear after the eclipse duration i ncreased above 1() mi nutes.

Fig. 12 and 13 exhibit the voltage differential of battery #2 for each orbit for the first and second occul tation period respect i vely. 'J 'he volt age differential for battery #2 behaved very similar to that of battery # 1.

Fig. 14 and 15 exhibit the voltage differential of battery three for each orbit for the first and second occultation period respecti vel y, Again, battery #3 exhibited similar behavior during these periods of the mission.

End-of-Night Battery Voltage

The end-of-night battery voltage (EONV) or end-of-discharge voltage (EODV) is the lowest voltage the battery reaches during the end of the eclipse period of each orbit. This parameter may be used as an efficiency or wearout indicator. The internal impedance of the batteries varies as a function of slalc-of-charge and it increases as the slalc-of-charge decreases. "1'bus, the higher the 1)01) the higher the internal impedance and hence the lower the EONV of the batteries. in addition, as the batteries age, it i s expected that the efficiency of the batteries decreases and the internal impedance increases. This results in lower EONV with ageing. This parameter is important in supporting the voltage requirements of the various satellite instruments.

Fig. 16 and 17 illustrate the EONV for each battery for each orbit for the first and second occultation period respectivel y. During both occultation periods the 1owcsI EONV was 27.52 V which occurred during the longest eclipse periods when the DOD was at the highest level (12 %).

Fig. 18 exhibits the cell voltage versus capacity discharged for six cells from the same manufacturing 10 I as the flight batteries. When the operating 1)01) was lcss than 5% the batteries operated at the initial knee of this curve. As the DOD increased the cells operated on the voltage plateau. This explains the higher EONV during the period of the occultation period with the shorter duration eclipses.

Conclusions

During the first two occultation periods the batteries on the TOPEX/POSEIDON satellite have been performing within the guidelines set by the Battery Management Team prior to launch. The degradation detected by the various battery parameters trended to date is none. The C/1) ratios were actively controlled within the appropriate limits. By actively managing the V/T levels the C/J) ratios were maintained on an average lower than 108.5. The net overcharge was minimized. 'J 'he peak charge current was maintained below ?0 A except for the safehold period (4 orbits at 30 A). The taper current of the batteries has been maintained at the levels of initial opcl-alien which indicates low rate of degradation. The voltage differential has been within 3 DN counts (16.5 mV) at all times except for eclipse duration lower than 10 minutes where it exhibited cusps 104 DN counts (22mV). The EONV was above 27.52 V at all times, which may also indicate a low degradation rate. 1 lowever, this concludes only 1/11 part of the total mission. Wc anticipate that with proper battery management the performance of the batter ics will continue to remain at optimum levels.

Acknowledgement

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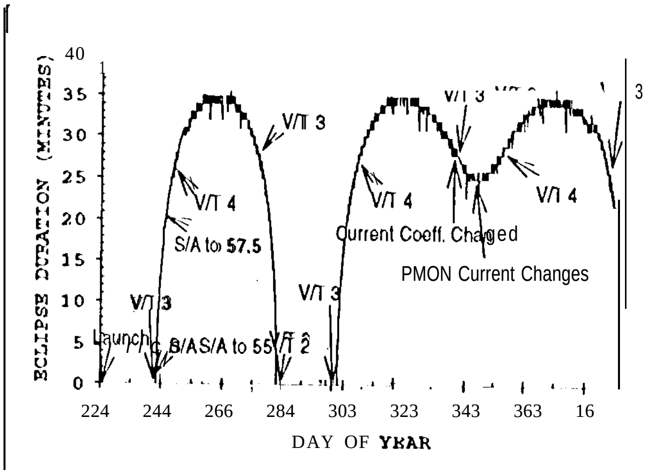

Fig. 1. Significant Events During the First Two Occultation Periods

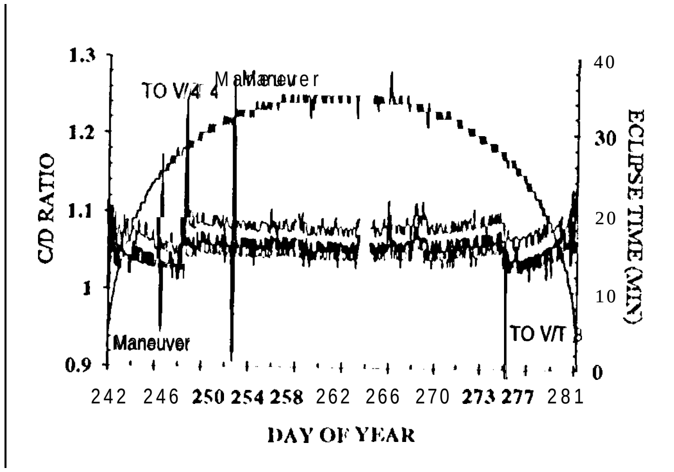

Fig. 2. Charge/Discharge Ratio of all 3 Batteries During Occultation Period # 1

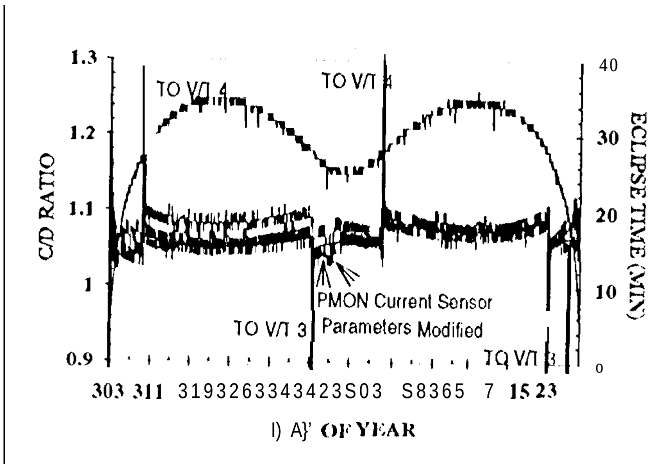

Fig. 3. Charge/Discharge Ratio of all 3 Batteries During Occultation Period #2

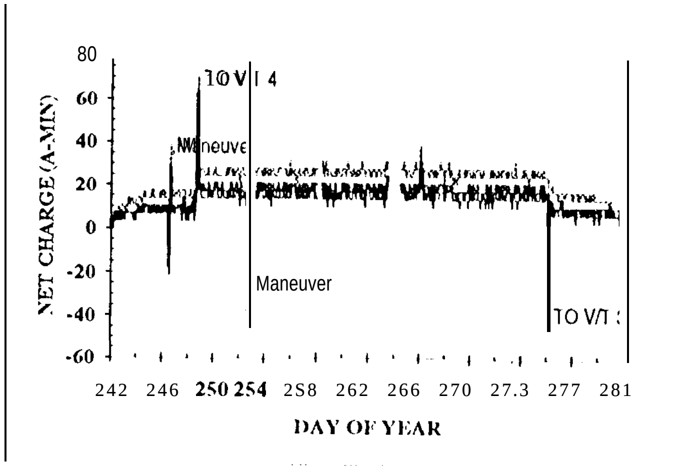

Fig. 4. Net Overcharge of all 3 Batteries During occultation Period # 1

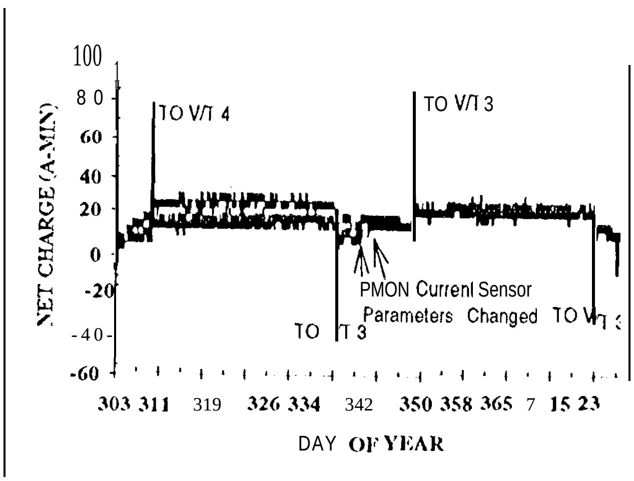

Fig. 5. Net Overcharge of all 3 Batteries During Occultation Period #2

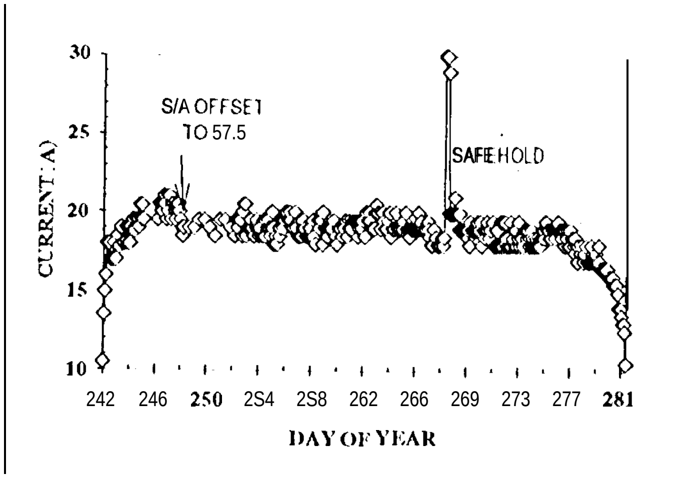

Fig. 6. Peak Charge Current of all 3 Batteries During Occultation Period # 1

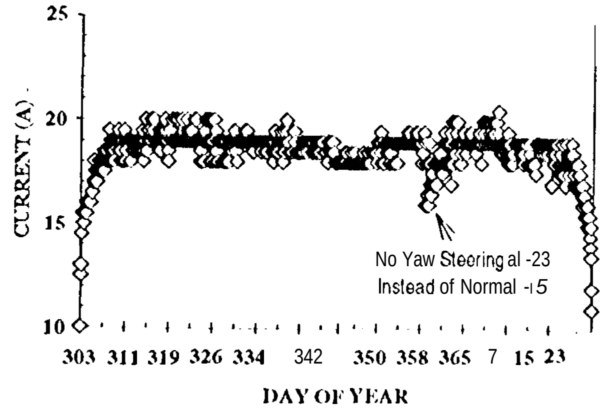

Fig. 7. Peak Charge Current of all 3 Batteries During Occultation Period #2

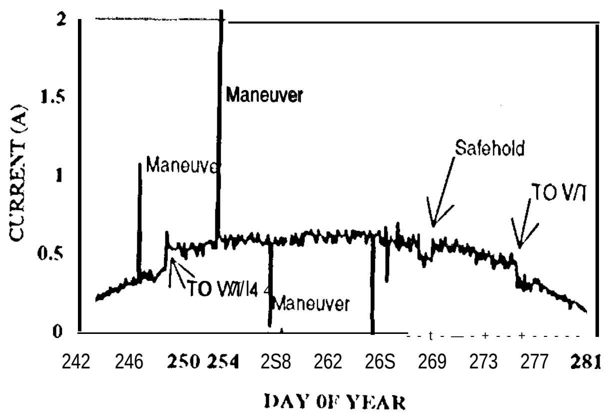

Fig. 8. Taper Current of all 3 Batteries During Occultation Period #1

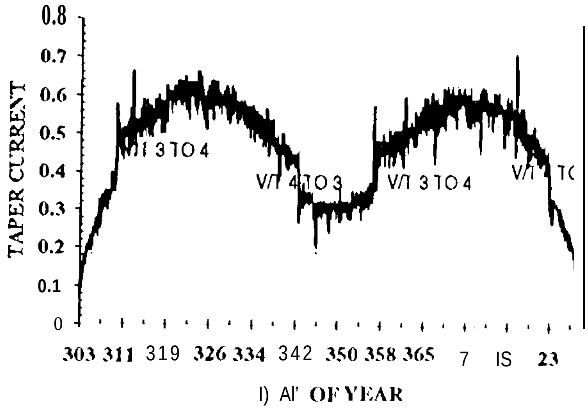

Fig. 9. Taper Current of all 3 Batteries During Occultation Period #2

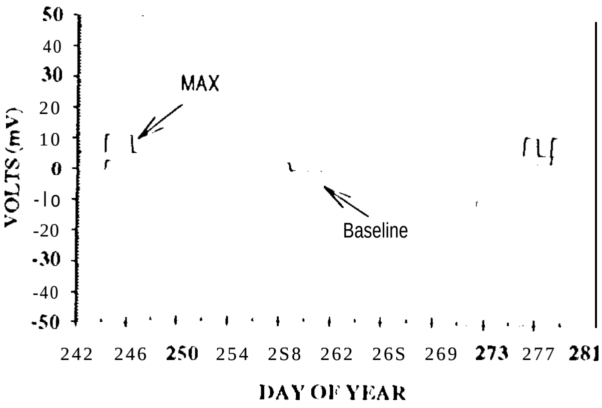

Fig. 10. Battery #1 Voltage Differential During Occultation Period #1

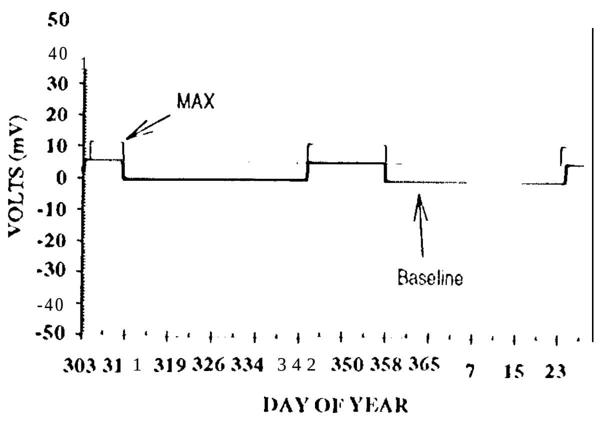

Fig. 11. Battery #1 Voltage Differential During Occultation Period #2

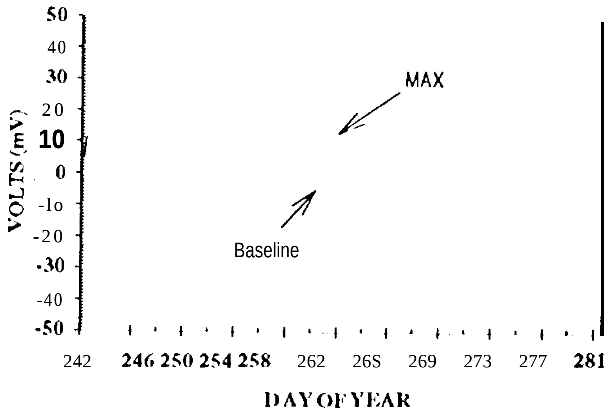

Fig. 12. Battery #2 Voltage Differential During occultation Period #1

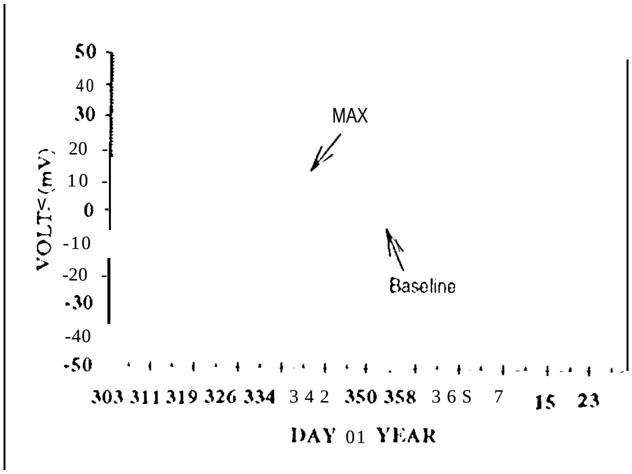

Fig. 13. Battery #2 Voltage Differential
During Occultation Period #2

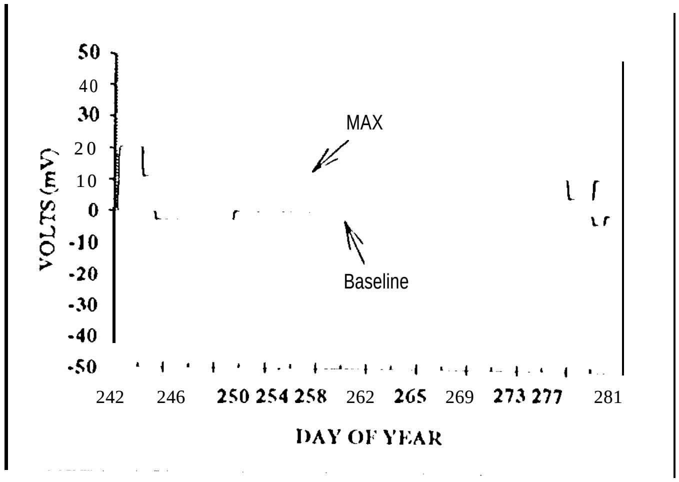

Fig. 14. Battery #3 Voltage Differential
During Occultation Period #1

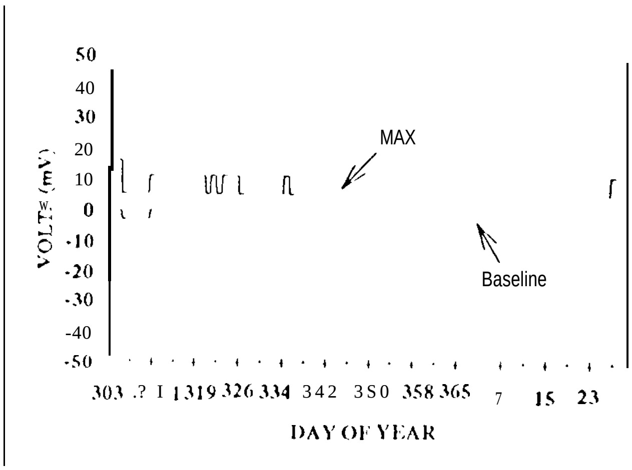

Fig. 15. Battery #3 Voltage Differential
During Occultation Period #2

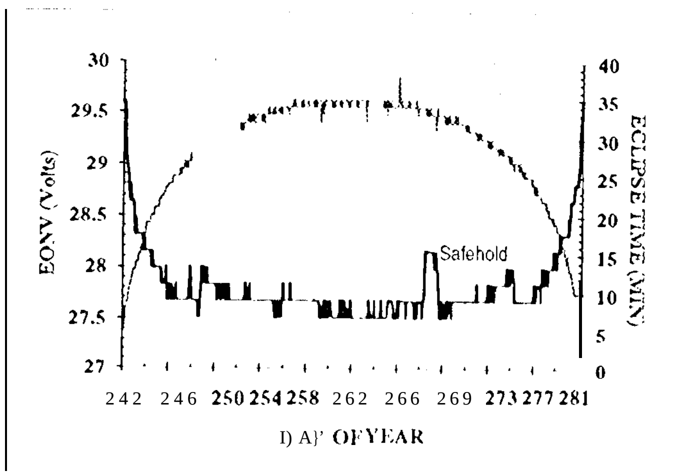

Fig. 16. Battery End-Of-Night Voltage
During Occultation Period #1

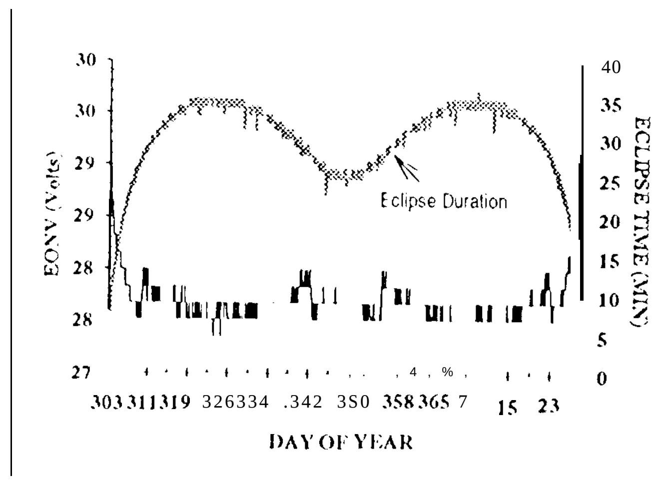

Fig. 17. Battery End-Of-Night Voltage
During Occultation Period #2

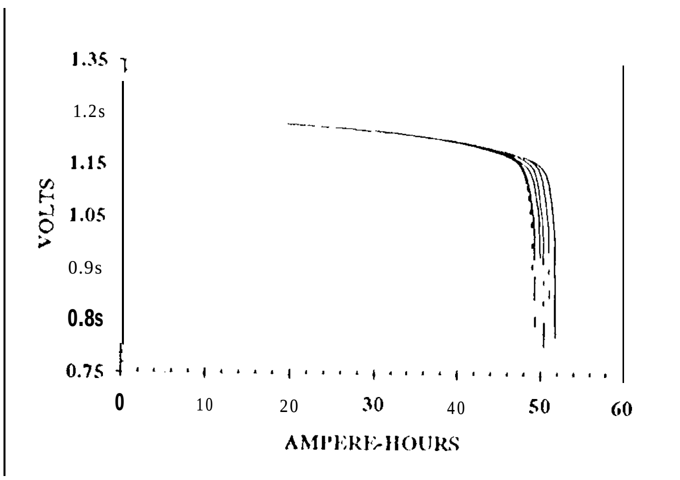

Fig. 18. Discharge Voltage Profile of Six TOPEX
Cells During a C/2 Discharge